Is the Power Density of Large Offshore Wind Farms Limited?

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Is the Power Density of Large Offshore Wind Farms Limited?

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Motivation

Adams and Keith, 2013:

"The results suggest that the maximum energy that can be extracted by turbine arrays at these scales is about 1 $W\,m^{-2}$."

Adams and Keith, 2013

Adams and Keith, Are global wind power resource estimates overstated? (2013)

Method

- Weather Research & Forecast (WRF) model
- Wind farm parametrisation from Adams 2007 (Turbine drag + TKE)

Simulations over the Great plains in winter/summer 2006

Power density estimation in function of:

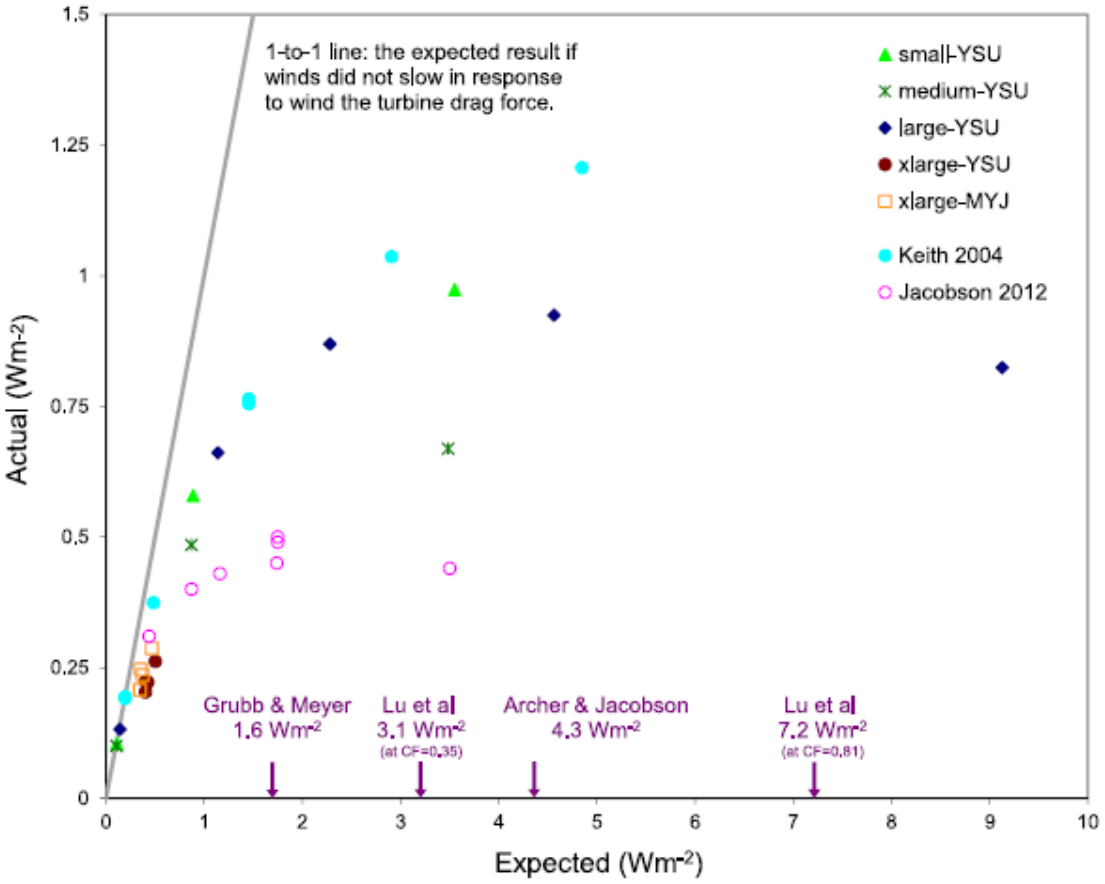
1) Wind farm size 10^3 – $10^5\,\mathrm{km}^2$
2) Turbine (2 MW turbines) density 0.25 – $16\,\mathrm{km}^{-2}$

Runs with and without wind farms to predict:

- Actual power density P_a (wake effects)
- Expected power density P_e (no wake effects)

Adams and Keith, 2013

Comparison between Expected and Actual power density gives:



Limit: $P_a \sim 1\,\mathrm{W\,m^{-2}}$

Horns Rev I $\left(20\,\mathrm{km^2}\right)$ has a measured power density: $3.98\,\mathrm{W\,m^{-2}}$

This would mean: That the power density of large wind farms is only 25% of that from regular wind farms

Was the analysis from Adams and Keith 2013 complete?

Does the power density converge to $1\,\mathrm{W\,m^{-2}}$ for different climates?

Experiment: WRF simulation for:

- 3 wind farm parametrisations
- 2 wind farm sizes
- 3 climates

Wind farm parametrisations:

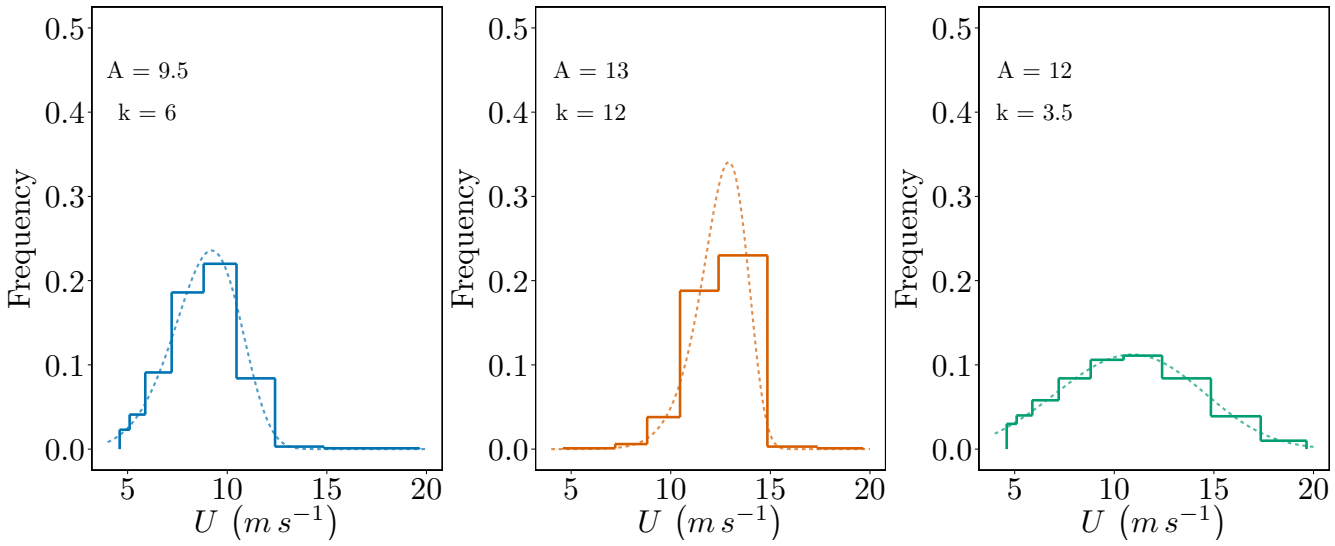
- Explicit Wake Parametrisation (Volker et al. 2014)
- WRF-WF scheme (Fitch et al. 2013)
- ROTOR-DRAG scheme: local drag only

Rectangular Wind farms (Nominal power density $6.4\ \mathrm{W\,m^{-2}}$):

- 2MW X 100
- 2MW X 3.600

Wind Climates:

Obtained from 9 idealised case simulations

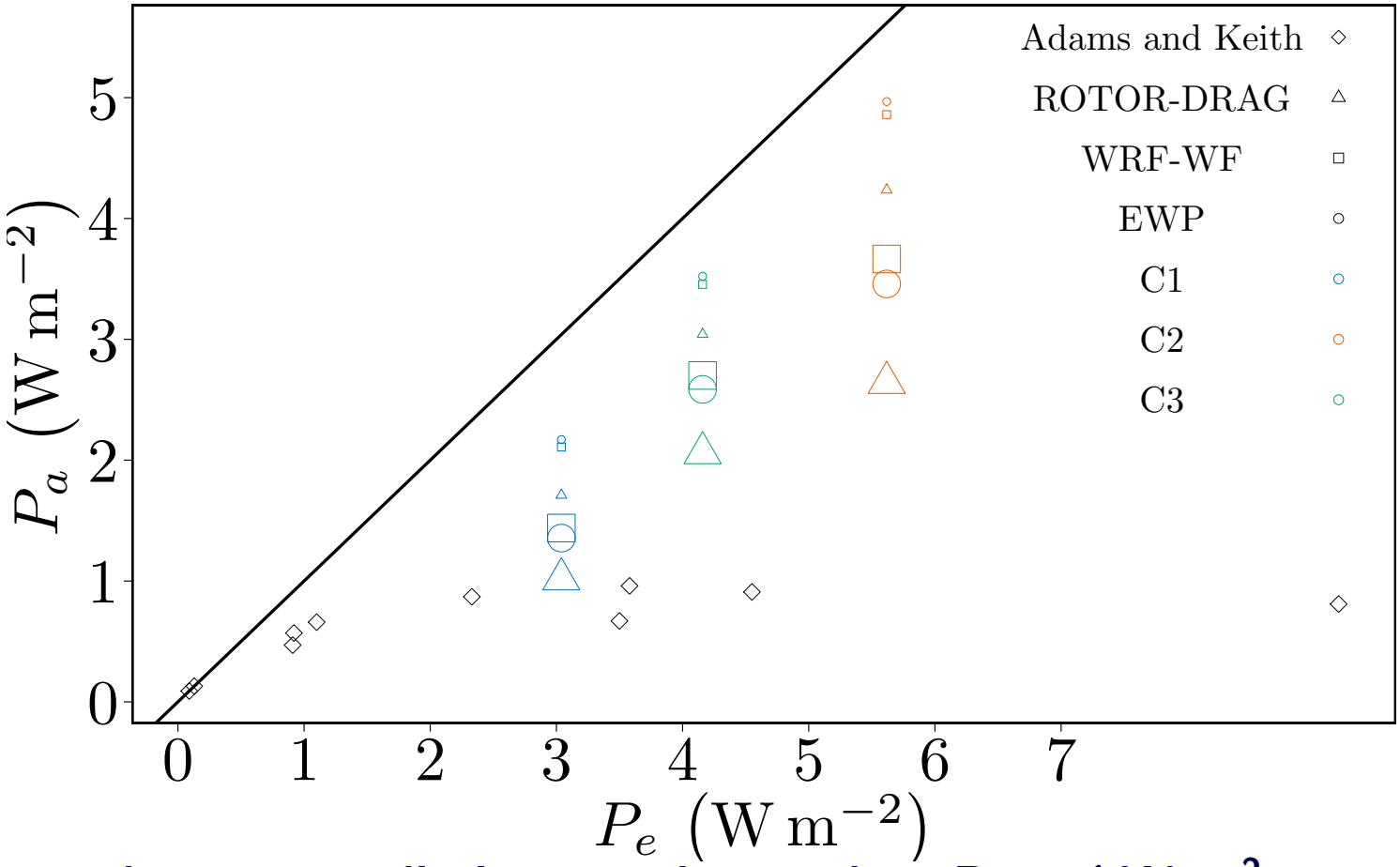


Results

Dots-size is related to wind farm size

Symbols represent the wind farm parametrisations

Colours indicate the wind climates



- **All actual power predictions are larger than $P_a = 1\,W\,m^{-2}$**
- **Clear (almost linear) dependency on the wind climate**
- **For C2 climate: $3.5\,W\,m^{-2}$ (100 Turbines) vs. $2.6\,W\,m^{-2}$ (3.600 Turbines)**

Conclusion

- The power density modelled with the mesoscale model is in line with observations ($3.5\,\mathrm{W\,m^{-2}}$ for 100 turbines, for the C2 climate (similar to that at HRI))
- The power density is a clear function of the climate

  $\Rightarrow$ Consequently, the study from Adams and Keith is incomplete
- The power density decreases by around 25%, for wind farms 36 times larger than HRI